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NAVY DEPARTMENT
BUREAU OF NAVAL WEAPONS
WASHINGTON, D.C.



WEAPON SYSTEMS ANALYSIS OFFICE

REPORT NO. 1-1-1

ANALYSIS OF STABILITY OF WEAPON SYSTEMS
AGAINST SHOCK AND VIBRATION

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NAWEPS

ANALYSIS OF STABILIZATION OF OPTICAL LANDING SYSTEMS
AGAINST SHIP ROLL AND PITCH - "CENTERLINE"
SYSTEM AND FLAT

Report No. R-5-63-2/2

BuWeps

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ABSTRACT

A study has been made of the stabilization of the Pilot Landing Aid Television System devised for monitoring carrier aircraft landings, and of the stabilization of a proposed, centerline-located Optical Landing System which might relieve pilots of looking to the side during a critical phase of the approach. Stabilization of the PLAT system is only partial, and the quantitative consequence is determined. The centerline-located OLS is shown to have lost its provision for simple accommodation of various H/E values and to be incapable of line-stabilization. However, point-stabilization, which is possible, is probably adequate.

INTRODUCTION

A Pilot Landing Aid Television System (PLAT) has been found to be a valuable aid in monitoring carrier landings. In PLAT an unmanned television camera is mounted essentially flush with the runway and on the runway centerline. To provide for keeping the camera pointed along the glide path as the carrier rolls and pitches the camera is merely tilted just as the lens box of the Optical Landing System (OLS) is tilted. However, the beam of the OLS is fan-shaped and always contains the stabilized point, whereas the beam of the camera is a pencil beam. Some form of "train" is needed to keep the camera looking at the stabilized point. An analysis is made in this report of the PLAT stabilization scheme.

The offset location of the mirror or lens of the OLS from the runway centerline (70 ft in the case of the CVA-63 installation) is thought to be disadvantageous to the pilot in the final portion of the approach because of requiring the pilot to look to one side. A proposal has evidently been made to locate, in effect, the OLS light source at the surface of the runway and on the centerline. The light source would produce a fan-shaped beam just as for the OLS. A minor variation of this system provides for a surface source on each side of the runway centerline. An analysis has been made of the stabilization features of such an OLS. Because of the similarity in location of the camera in PLAT and of the light source in the proposed OLS, both analyses have been included in this same report.

PIAT STABILIZATION

The PIAT camera on a level ship looks along the flight glide path. On a pitching and rolling ship it is desired to keep the camera continuously looking along the fixed glide path. However, the only "freedom" of motion relative to the deck provided for the camera is tilt motion in a plane perpendicular to the deck through the runway centerline, and the control of this tilt motion is obtained from the point-stabilized OLS. It is understood from reference (a) that the tilt or elevation of the pencil beam of the centerline camera is at all times equal to the tilt of the light beam from the offset OLS.

The analysis is similar to that employed in references (b) and (c). The location of the centerline cameras is shown in Figure 1. One is referred to as "regular" and one as "back up" in reference (a). Which is which is not stated. An installation has been made on the CVA-64, which is similar to the CVA-63 studied in connection with the OLS. The dimensions already familiar for the CVA-64 installation are as follows (refer to Figure 1):

α	F	E	G	H	A'	A''
11° 20'	433'	252.5'	66'	51'	441.6"	506.1"

For the centerline installation of cameras:

$$\begin{aligned} [A' - (F-E) \cos \alpha] \cos \alpha &= B' \\ [A' - (F-E) \cos \alpha] \sin \alpha &= B'' \end{aligned} \quad (1)$$

with corresponding relationships for A'', D'', and B''. The resulting additional parameters become:

D'	D''	B'	B''
6.8'	72.1'	52.0'	65.1'

A coordinate system was chosen fixed in the ship with origin on the roll axis at a point directly over the pitch axis, with the x-axis coinciding with the roll axis, positive y-axis extending to port, and z-axis perpendicular to the deck, as in Figure 2.

The runway camera locations in this coordinate system are L_1 (D' , B' , H) and L_2 (D'' , B'' , H). A point on the glide path or axis of the camera beam is $P(x, y, z)$. The equation of the camera beam axis is then

$$-(z - H) \cot \beta = (y - B') \csc \alpha = (x - D') \sec \alpha \quad (2)$$

As in previous OLS studies, an $X''Y''Z''$ coordinate system (Figure 3) was chosen fixed in space (not rolling or pitching), with the origin O'' located at the "center" of pitch, positive X'' -axis forward, and positive Y'' -axis to port. For transformation of the equation of the rolling and pitching beam axis to the $X''Y''Z''$ coordinate system,

$$x = X'' \cos \psi - Z'' \sin \psi$$

$$y = Y'' \cos \theta + Z'' \cos \psi \sin \theta + X'' \sin \psi - (C-H) \sin \theta$$

$$z = Z'' \cos \psi \cos \theta + X'' \sin \psi \cos \theta - Y'' \sin \theta - (C-H) \cos \theta$$

The camera beam axis then is represented by the two equations for two planes intersecting along the axis:

$$V = (X'' \cos \psi - Z'' \sin \psi - D') \tan \beta + [Z'' \cos \psi \cos \theta + X'' \sin \psi \cos \theta - Y'' \sin \theta - (C-H) \cos \theta - H] \cos \alpha = 0 \quad (3)$$

$$W = [Y'' \cos \theta + Z'' \cos \psi \sin \theta + X'' \sin \psi \sin \theta - (C-H) \sin \theta - B'] \tan \beta + [Z'' \cos \psi \cos \theta + X'' \sin \psi \cos \theta - Y'' \sin \theta - (C-H) \cos \theta - H] \sin \alpha = 0$$

It is of interest to note whether, from the equations developed, the camera beam does actually point along the glide path when the camera has the same tilt as the OLS lens box. This can be most readily noted when the ship is level ($\psi = \theta = 0$) from

$$\begin{aligned} V_0 &= (X'' - D') \tan \beta + (Z'' - H) \cos \alpha = 0 \\ W_0 &= (Y'' - B') \tan \beta + (Z'' - H) \sin \alpha = 0 \\ (X'' - D') \sin \alpha - (Y'' - B') \cos \alpha &= 0 \end{aligned} \quad (5)$$

The typical tilt angle β considered in reference (b) is 2.5° . The point stabilized in that reference, 2500 ft aft of the lens, had the coordinates (-2447, -439.8, 222.5). From equations (5) the coordinates of a point on the camera beam axis 2447 ft aft of the origin O" are (-2447, -439.8, 219.1) for the camera L₁, and (+2447, -439.8, 223.1) for L₂. It can be seen that the forward camera, L₂, does look approximately along the desired glide path, at least when the angle γ (for hook-to-eye adjustment) is set equal to zero. This could have been expected, since the distance A" (marked B in reference (a)) is approximately equal to distance A in reference (b). However, the aft camera looks below the desired glide path with $\gamma = 0$. The difference is small.

For small pitch and roll of the ship, useful approximations to the deviation of the camera beam axis from a steady glide path can be obtained from a differential analysis.

$$\begin{aligned} \partial V / \partial \beta d\beta + \partial V / \partial \psi d\psi + \partial V / \partial \theta d\theta + \partial V / \partial Y'' dY'' + \partial V / \partial Z'' dZ'' &= 0 \\ \partial W / \partial \beta d\beta + \partial W / \partial \psi d\psi + \partial W / \partial \theta d\theta + \partial W / \partial Y'' dY'' + \partial W / \partial Z'' dZ'' &= 0 \end{aligned}$$

The differential coefficients are:

$$\begin{aligned}
 \partial V / \partial \beta &= (X'' \cos \psi - Z'' \sin \psi - D') \sec^2 \beta \\
 \partial V / \partial \psi &= (-X'' \sin \psi - Z'' \cos \psi) \tan \beta \\
 &\quad + (-Z'' \sin \psi \cos \theta + X'' \cos \psi \cos \theta) \cos \alpha \\
 \partial V / \partial \theta &= [-Z'' \cos \psi \sin \theta - X'' \sin \psi \sin \theta - Y'' \cos \theta - (G-H) \sin \theta] \cos \alpha \\
 \partial V / \partial Y'' &= (-\sin \theta) \cos \alpha \\
 \partial V / \partial Z'' &= (-\sin \psi) \tan \beta + (\cos \psi \cos \theta) \cos \alpha \quad (7)
 \end{aligned}$$

$$\begin{aligned}
 \partial W / \partial \beta &= [Y'' \cos \theta + Z'' \cos \psi \sin \theta + X'' \sin \psi \sin \theta - (G-H) \sin \theta - B'] \sec^2 \beta \\
 \partial W / \partial \psi &= (-Z'' \sin \psi \sin \theta + X'' \cos \psi \sin \theta) \tan \beta \\
 &\quad + (-Z'' \sin \psi \cos \theta + X'' \cos \psi \cos \theta) \sin \alpha \\
 \partial W / \partial \theta &= [-Y'' \sin \theta + Z'' \cos \psi \cos \theta + X'' \sin \psi \cos \theta - (G-H) \cos \theta] \tan \beta \\
 &\quad + [-Z'' \cos \psi \sin \theta - X'' \sin \psi \sin \theta - Y'' \cos \theta - (G-H) \sin \theta] \sin \alpha \\
 \partial W / \partial Y'' &= (\cos \theta) \tan \beta + (-\sin \theta) \sin \alpha \\
 \partial W / \partial Z'' &= (\cos \psi \sin \theta) \tan \beta + (\cos \psi \cos \theta) \sin \alpha \quad (8)
 \end{aligned}$$

The mean values of pitch ψ and roll θ are zero, so that

$$\begin{aligned}
 \partial V / \partial \beta &= (X'' - D') \sec^2 \beta \\
 \partial V / \partial \psi &= (-Z'') \tan \beta + (X'') \cos \alpha \\
 \partial V / \partial \theta &= (-Y'') \cos \alpha \\
 \partial V / \partial Y'' &= 0 \\
 \partial V / \partial Z'' &= \cos \alpha \quad (9) \\
 \partial W / \partial \beta &= (Y'' - B') \sec^2 \beta \\
 \partial W / \partial \psi &= (X'') \sin \alpha \\
 \partial W / \partial \theta &= [Z'' - (G-H)] \tan \beta + (-Y'') \sin \alpha \\
 \partial W / \partial Y'' &= \tan \beta \\
 \partial W / \partial Z'' &= \sin \alpha \quad (10)
 \end{aligned}$$

The deviation of the camera beam axis from the glide path is then given by (from equations (5), (6), (9), (10)):

$$dY'' = -Z'' \tan \alpha d\psi - [Z'' - (g-H)] d\theta \quad (11a)$$

$$dZ'' = Y'' d\theta - (X'' - Z'' \tan \alpha \sec \alpha) d\psi \\ - (X'' - D') \sec \alpha \sec \alpha d\beta, \quad (11b)$$

where the tilt deviation $d\beta$ from "basic" angle is the same $d\beta$ found for the OLS in reference (b) (since it is taken from the OLS); namely,

$$d\beta = -0.954 d\psi + 0.1715 d\theta \quad (12)$$

To illustrate the analysis of accuracy of stabilization of the PLAT system, the deviation, vertically and laterally, of the camera beam axis from the steady glide path will be determined at the point 2500 ft aft of the lens of the OLS, for the forward camera, since this camera was found to look most nearly along the glide slope. As in reference (b) the largest roll angle $d\theta$ believed reasonable for flight operations was taken at 4° , and the largest pitch angle $d\psi$ as about 2° . The deviations are then:

deviation, for	vertical (dZ'')	horizontal (dY'')
$+4^\circ$ roll	$+0.15$ ft	-14.6 ft
$+2^\circ$ pitch	$+0.10$ ft	-1.6 ft

The horizontal deviation here due to roll will be quite noticeable. However, as the aircraft approaches the ramp ($Z'' = 96.9$ ft) the horizontal deviation dY'' for $+4^\circ$ roll is -5.7 ft. Angular deviation as seen by the camera is not greatly different at the two distances, but the absolute deviation is probably less noticeable relative to the larger appearing aircraft.

CENTERLINE OLS

The proposed OLS installed on the runway centerline, approximately flush with the runway, would employ a fan-shaped light beam just as does the offset OLS. It is understood that the presentation would be essentially a parallax presentation. However, because the optical glide path is not offset from the axis of the light beam, as in the present OLS, variations in H/E distance can not be simply accommodated by "rolling" the fan-shaped beam (making γ a suitable value). Further, it is not feasible to line-stabilize a centerline - located OLS. This can be seen quite readily from reference (c), where equation (13) shows that for $C=0$ the fan-shaped light beam would theoretically be rolled into a vertical plane as the ship rolls from level (or $\beta=0$). However, the proposed OLS can be point-stabilized, and the analysis of reference (b) is applicable when the appropriate values of B and D are inserted.

From reference (b) the required tilt deviation $d\beta$ is given by (for small β):

$$d\beta = \frac{-X'' d\psi + Y'' d\phi}{(X'' - D') \cos \alpha + (Y'' - B') \sin \alpha} \quad (13)$$

where the coordinates of a point $P(X'', Y'', Z'')$ on the glide slope are related by equations (5). Reference (b) found some preference for choice of the stabilized point about 1000 ft aft of the light source. To illustrate the determination of the required pitch and roll correction factors for a centerline OLS, the previously found camera positions L_1 (6.8, 52.0, 51) and L_2 (72.1, 65.1, 51) will be used for light source locations. The stabilized point 1000 ft aft of each light source will have the respective positions P_1 (-993.2, -148.4, 113.4) and P_2 (-927.9, -135.3, 113.4). The calculated "correction factors" are then

"correction factor"	pitch	roll
aft light source (L_1)	-0.004	+0.1470
forward light source (L_2)	-0.021	+0.1304

A suggested variation of the centerline OLS would employ two light sources astride the runway centerline. It will be supposed that each source is spaced a distance s from the runway centerline and that both are a distance A' forward of the ramp. If L_1 is the source on the port side of the runway and L_2 that on the starboard side:

$$\begin{aligned} D_2' &= D_1' + 2s \sin \alpha \\ B_2' &= B_1' - 2s \cos \alpha \end{aligned} \quad (14)$$

When these expressions are inserted in the expressions for the pitch and roll correction factors it is found that the latter are identical for both of the abreast light sources. Thus the two fan-shaped beams from the two sources should at all times partially overlap. Each source produces its separate identical parallax presentation.

CONCLUSIONS

An analysis has been made of stabilization of the PLAT system and of a proposed "centerline" located OLS, based on previous studies of stabilization of the OLS. The major conclusions reached are as follows:

(1) The PLAT system using only the tilt signal from the OLS, is only partially stabilized. As the ship rolls the camera beam axis swings from side to side across the intended glide path. The amount of the lateral displacement of the camera beam crosshairs from an approaching aircraft on the intended glide path is expected to be distinctly perceptible at maximum swing. Actual trials should determine if the perceptible displacement is operationally troublesome.

(2) The proposed, centerline-located OLS can be point-stabilized basically similarly to the existing, offset-located OLS. The "pitch and roll correction factors" have different values for the different systems.

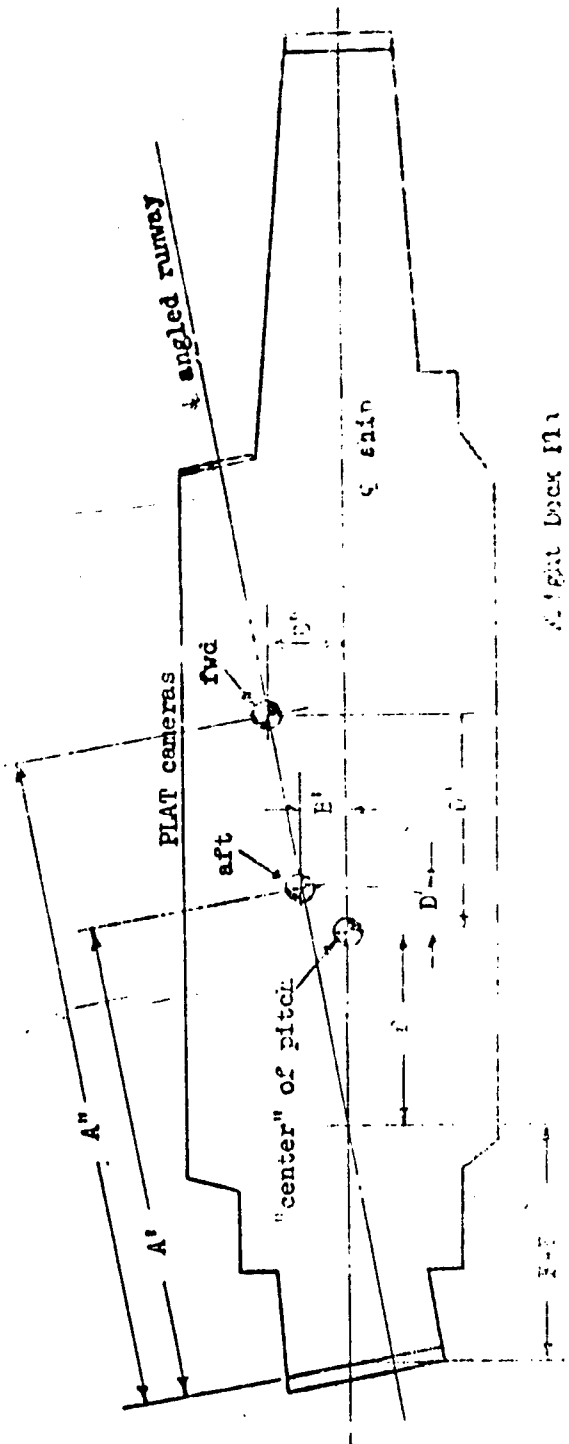
(3) The proposed, centerline-located OLS can not provide for easy adjustment of look-to-eye (H/E) distance by means of "rolling" the fan-shaped beam.

(4) The proposed, centerline-located OLS can not be line-stabilized. However, point stabilization has appeared to be adequate.

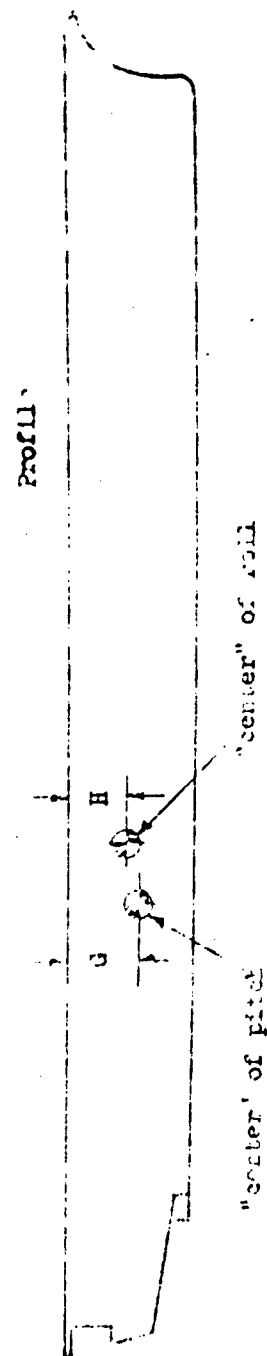
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REFERENCES

- (a) NAEL(SI) Report ENG-6932 dtd 15 Oct 1962 on "Installation Criteria for Shipboard PLAT (Pilot Landing Aid Television) System".
- (b) NavWeps Report No. R-5-62-39, dtd Oct 1962 on "Analysis of Stabilization of Optical Landing System Against Ship Roll and Pitch".
- (c) NavWeps Report No. R-5-63-2, dtd Jan 1963 on "Analysis of Stabilization of Optical Landing System Against Ship Roll and Pitch - Line Stabilized Version".



Flight Deck Plan



Profile

Figure 1

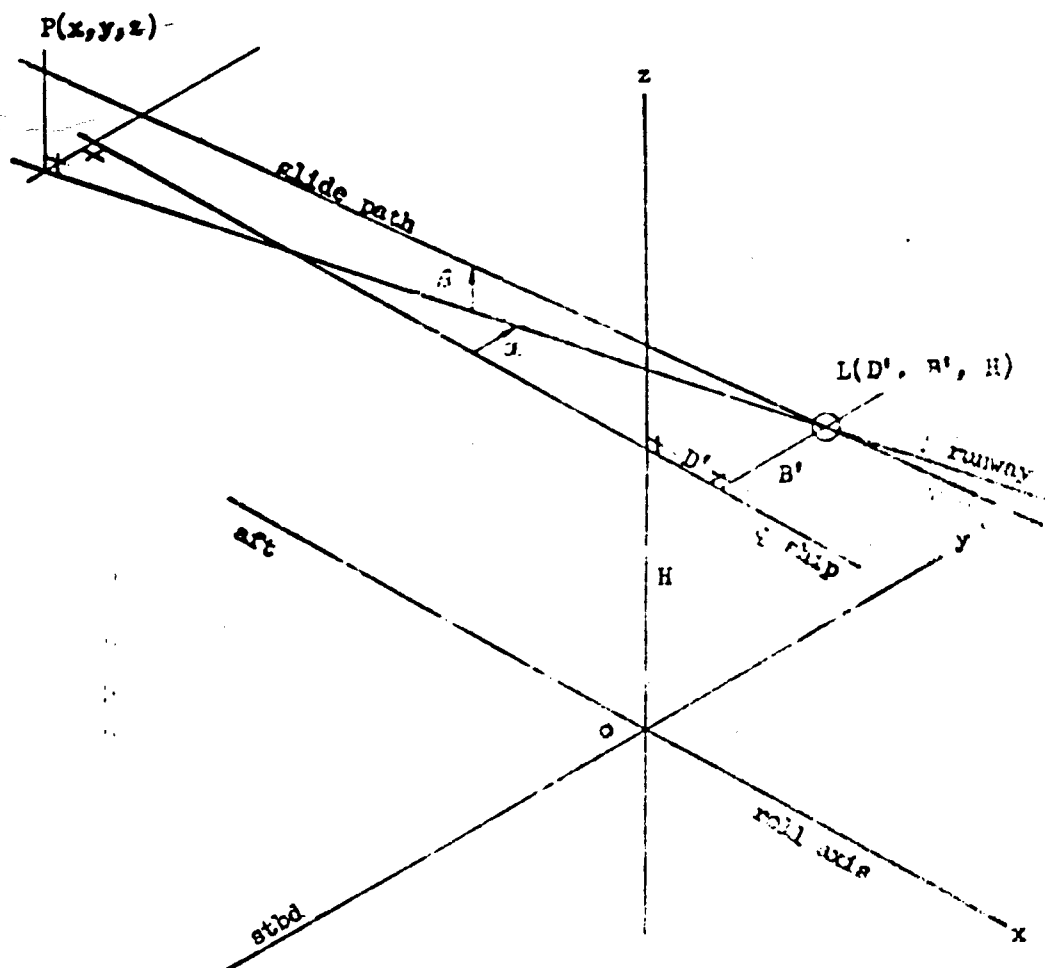


figure 2

Runway and eddie path
Relative to Ship

P = point on glide path
L = OLS light source, or
PLAT camera
O = origin, on ship roll
axis, directly over
pitch axis

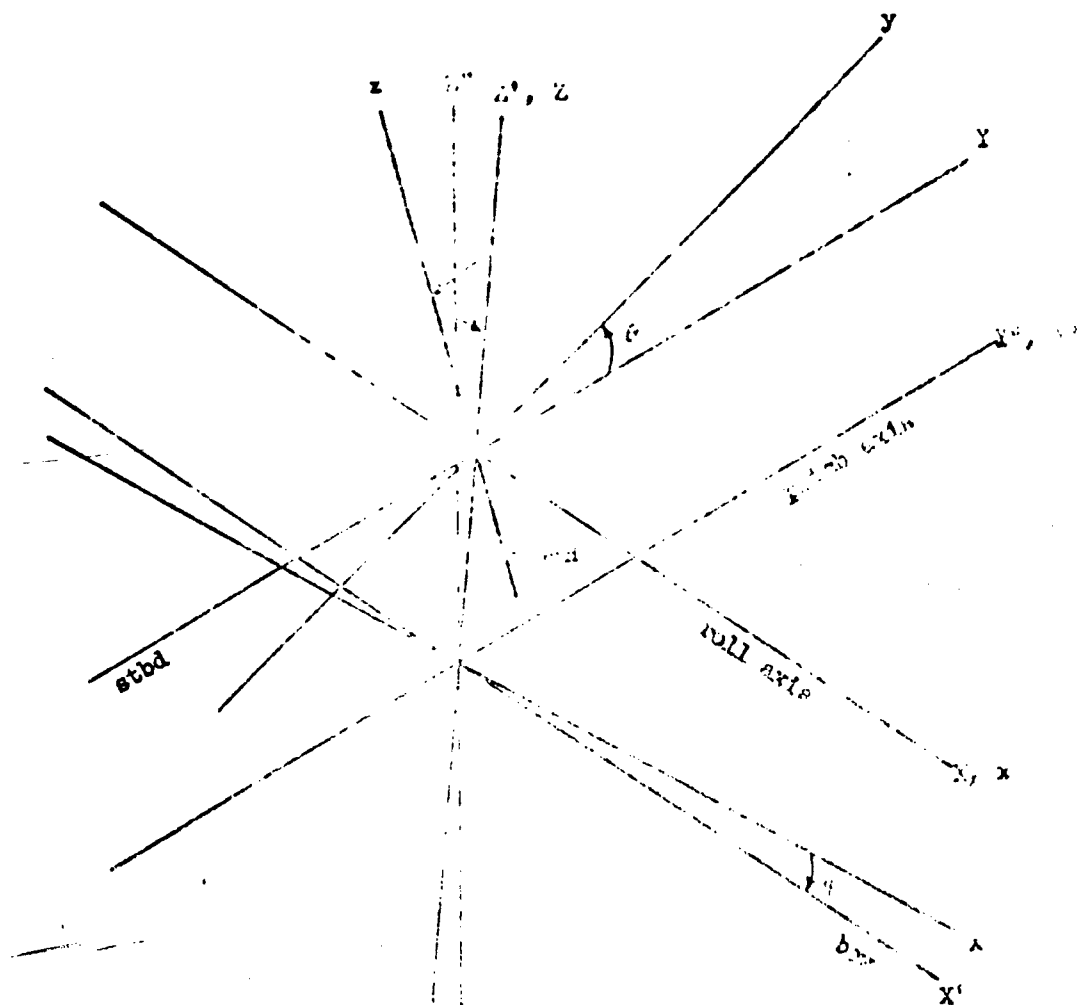


Figure 3

Coordinate Frames of Reference

θ pitch angle
 ϕ roll angle
 ψ yaw angle

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